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## The Hybrid Automobile: An In-Depth Analysis of the It Works and Where it is Going

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# **The Hybrid Automobile:**

**An In-Depth Analysis of How It Works and Where It Is Going**

By Nick Northington

Senior Honors Project

May 2, 2005

# Table of Contents

|                                                     |    |
|-----------------------------------------------------|----|
| Preface.....                                        | 2  |
| Introduction.....                                   | 3  |
| History of the Hybrid.....                          | 3  |
| Why A Hybrid?.....                                  | 6  |
| Today’s Model Technology: Hybrid Synergy Drive..... | 9  |
| Today’s Hybrid Market.....                          | 12 |
| The Future.....                                     | 14 |
| Works Cited.....                                    | 17 |
| Appendix 1.....                                     | 18 |
| Appendix 2.....                                     | 18 |
| Appendix 3.....                                     | 19 |

## **Preface**

Since I can recollect, I have always had a passion for cars. My first word was “caw,” and the day I turned 16 was perhaps the most anticipated day in my life. Since I was a child, I received a subscription and read diligently each month one of the major automotive magazines – Motor Trend, Car and Driver, or Road & Track. I came to college uncertain of my major, but I decided that it would be foolish of me to try to do anything that didn’t have potential for the automobile industry. So I changed my focus from pre-medicine to business, and I decided to double major in Marketing and Finance. With these majors, I saw potential to work in the industry at the corporate level, from an advertising position to a managerial position.

For my University Honors Senior Project, I knew that I had the opportunity to work with what I enjoy, so I decided that I should pursue research in the most dynamic segment of the automobile industry – the hybrid automobile. We are living through a trying time, a time that will decide the direction of future engine technology. Every month, the automobile publications release upcoming news and pictures of the latest hybrids. With timeliness in consideration, I acknowledge that this report will be outdated within the year. Through my analysis and research, I hope to educate you, my audience, about the exciting prospects of the hybrid automobile and the probability that you will be driving one in the near future.

## **Introduction**

The hybrid automobile is quickly becoming the newest trend in the automobile industry. Hybrids dominate industry buzz, appearing on the covers of numerous magazines and winning multiple automotive awards. Whether inventing their own hybrid technology or licensing others' technology, nearly every major automobile manufacturer is announcing plans to participate in the trend. The root of this trend can be attributed to the diminishing state of the world's oil reserves and the pollution problems caused by automobile emissions. Automobile manufacturers are finally responding by offering products that ameliorate emissions problems and use less gasoline. The answer in Europe continues to be improved diesel fuel and diesel engine technology. However, America has a different answer – the hybrid automobile.

Why is the hybrid significant? In the United States, cars are necessities for most people, but are major purchase decisions. Most consumers educate themselves about the car that they plan to buy prior to the purchase. If the current trend continues, whether or not to include a hybrid powertrain in an automobile will be a significant choice that consumers must make within the next decade. Consequently, it is critical that educated consumers understand where the hybrid comes from, the advantages to owning one, how it works, the current nature of the hybrid market, and the future of hybrid technology.

## **History of the Hybrid**

The hybrid derives from the old idea of adding an electric motor to facilitate the manner in which a gasoline engine-powered automobile functions. Many people and companies have played with the technology over time, developing their own versions of

the technology. However, the gasoline internal combustion engine, which has remained virtually unchanged for the past century, has always served as the primary engine technology in the U.S. used in cars and light trucks. Of course advances in technology have been applied to make the engine cleaner, lighter, and more efficient, but the principle technology remains unchanged. In the past, the time has not been right for hybrids because they have been too expensive to produce, and few consumers have demanded them. Today, however, these two factors have converged; manufacturers have finally been able to supply hybrid technology, and consumers have finally demanded it. America is becoming more concerned about a market dominated by gas-guzzling trucks and rising fuel prices.

The hybrid idea dates back to the time of the first automobiles. In 1905, H. Piper discovered a way to make a vehicle accelerate from 0-25 miles per hour in less than 10 seconds, which was very quick for the time. He applied for a patent to protect this technology in which an electric motor augmented the gasoline engine, increasing its speed. Mr. Piper's idea was ahead of its time though, as oil was not endangered and electricity was expensive.

Another early pioneer of hybrid technology was Ferdinand Porsche, an inventor for Austria's Jacob Lohner & Co. He engineered the first fundamental hybrid, in which a gasoline engine powers an electric generator that produces electricity for the electric motors. This system by-passed complicated transmissions of the time, using electric motors to drive the wheel hubs. These cars were called Lohner-Porsches.

Automobile companies internationally developed hybrid technology. General Electric in America, Siemens-Schuckert Company in Germany, and Galt Motor Company

in Canada were all working on their own versions of hybrids in the early 1900's (Brief History). Most hybrids at the time were series hybrids, where the gasoline engine is not directly coupled to the drive wheels. The engine drives an electric generator, which in turn powers an electric motor (Irick). This electric motor in turn drives the car. Galt Motor Company strove to perfect the series hybrid in 1914, but could not engineer a hybrid fast enough to keep up with competition.

Woods Motor Vehicle Company developed the parallel hybrid in 1917, meaning that the gasoline engine and electric motor work together to drive the automobile. The electric motor could drive the car up to a certain speed, after which the gasoline engine couples to the transmission increasing the speed. However, Woods had a similar problem to Galt Motor Company's problem; the technology's top speed was only 35 miles per hour, and competing gasoline engines were faster.

These hybrid technologies were put to rest in the automobile industry until 1997 when Toyota introduced its Prius, the world's first production hybrid. This car was a true hybrid, which could function with its gasoline engine only, its electric motor only, or utilize both simultaneously. Honda later introduced its Insight in 2000 and its Civic Hybrid in 2003, both of which are mild hybrids where the electric motor can never move the car on its own.

Toyota has since released its second-generation Prius in 2004, utilizing similar series and parallel hybrid technologies that it calls "Hybrid Synergy Drive" (Brief History). Ford licensed Toyota's technology to use in its Escape Hybrid. The Escape was released in November of 2004, making it the world's first hybrid sport utility vehicle. Toyota released the Highlander and the Lexus RX 400h sport utility vehicles this year as

well, using the same technology with a different engine. Honda released its 2005 Accord Hybrid that uses the mild hybrid technology seen in its Civic Hybrid. The final hybrid offered today is the 2005 Chevrolet Silverado Hybrid, which uses an electric motor to start the engine that can also that can double as a generator for worksite activities.

This history of hybrid engine development has set the stage for automakers to build many different types of hybrid powertrains. Today's offering of hybrids is limited, but other auto manufacturers are feeling the pressure to offer a hybrid from their brand. As a result, news is being released monthly regarding which manufacturers will offer hybrids and which technology they will use.

### **Why A Hybrid?**

Very few consumers would pay the premium for a hybrid automobile unless they were educated about the advantages of owning a hybrid. Many consumers are still under the impression that you have to plug the engines in and charge them. This was only true of the earlier electric cars, none of which are still produced. Not only are they just as easy to use as normal cars now, but hybrids provide environmental incentives, ride quality incentives, tax incentives, and potential performance incentives.

Hybrids are environmentally friendly and are often dubbed "green machines." They provide much cleaner exhaust emissions than your typical gasoline internal combustion engine. The degree of hybrid integration will of course depend on the emissions improvements. For example, a Prius can run on just its electric motor at certain speeds, which will emit little or no exhaust fumes. The Silverado Hybrid, however, always runs on its gasoline engine, emitting exhaust fumes constantly. Hybrids



are also more environmentally friendly because they attain better fuel economy, which uses less gasoline in a world of depleting oil reserves. The Prius can reach over 50 miles per gallon (mpg), the Insight measures approximately 66 mpg, and most other hybrid offerings post mid to low thirties miles per gallon (Eisenstein, 103-105).

Automobile technology has progressed to great levels, making the ride quality in many luxury automobiles nearly free of any bumps or blemishes in the road. Many hybrid automobiles though can provide a much quieter ride, depending on the hybrid technology used. If the electric motor(s) drive the vehicle at certain speeds, ride quality is greatly enhanced due to lack of noise and vibrations. An internal combustion engine inherently makes more noise and vibrates at greater levels than an electric motor. Compare the ride of an electric golf cart to that of a gas powered golf cart, and apply it to an automobile. For example, the new Lexus RX 400h “is also tremendously smooth and quiet – maybe even a bit smoother and quieter than the very smooth and very quiet RX 330” (Huffman).

Another advantage to owning a hybrid that many consumers are unaware of is the government’s \$2,000 tax deduction, during the first year of use. This is the U.S. government’s way of encouraging sales of low-pollution cars and trucks. Consumers can essentially consider this a rebate to the premium that they pay for purchasing a hybrid automobile. The deduction is scheduled to fall to \$500 for 2006, after which it will cease to exist (Bennett).

An advantage to hybrid engine technology that has yet to be fully realized is the potential of performance improvements. Hybrids still carry the stigma that their engines are inherently slower than naturally aspirated gasoline engines. This stereotype was

fueled by older electric cars that had 0 to 60 miles per hour (mph) times of over 12 seconds. Fortunately, today's slowest hybrids hit 60 mph in under 11 seconds. Toyota's recent Prius hits 60 mph in 10 seconds, and Honda's Civic Hybrid and Insight hit 60 mph in just under 11 seconds (See Appendix 1). Relative to gasoline engines, these times are still slow, but the industry's newest hybrid offerings from Toyota, Lexus, and Ford are actually quicker than their gasoline counterparts. The Toyota Highlander can hit 60 mph in 6.6 seconds, "an elbow-scratching 2.5 seconds quicker than the 3.0-liter V-6 4WD example we tested..." (Reynolds, 149). For any automobile, this time is fast, but for a truck, this is very fast. The reason for these improved performance times is due to the immediate torque that is available with an electric motor. A traditional internal combustion engine takes time to rev up before its maximum torque is reached. However, an electric motor does not have to rev, providing this immediate torque for improved speed. Honda is considering these performance advantages in building its next exotic performance car, the Acura NSX. The company discussed the possibility of powering the rear wheels by a combination of gas engine and electric motor while the front wheels could be driven by electric power only (Eisenstein, "Everything"). Porsche is also toying with the idea of a hybrid automobile, but, of course, it must provide some measure of performance for the sports car company. Vice President Wendelin Wiedeking said, "We have several options, but the technology must fit. It must add to performance" (qtd. in "Porsche" 28).

The advantages of owning a hybrid are greater than the disadvantages, but a few key disadvantages keep many people away. The price premium is often greater than the potential gas savings could ever amount to in the life of a car. The new Toyota

Highlander Hybrid will cost at least \$4,000 to \$5,000 more than the corresponding Highlander without the hybrid engine. It is virtually impossible to justify this price premium in fuel costs savings, and even more so when replacement of the battery packs must be factored over the first approximately 100,000 miles (Reynolds, 149).

Another disadvantage is the added weight of the battery pack and the electric motors, which damages performance. The Prius has two electric motors, and the Highlander and Lexus 400h have 3 electric motors. On these sport utility vehicles, this extra hardware weighs in at over 300 extra pounds on the vehicle (Huffman). In many cases, however, this weight disadvantage is mitigated by the performance increase by the hybrid powertrain.

The final disadvantage is the marginal loss of power due to the state of charge of the battery. If driven hard for an extended period of time, a hybrid's power can be reduced to only the power of its gasoline engine. Aggressive driving will drain the juice from the battery, which will in turn render the electric motor(s) useless, until recharged. Typically, there are only two ways for the battery to be recharged: regenerative braking or the gasoline engine, both of which take time.

### **Today's Model Technology: Hybrid Synergy Drive**

Toyota's Hybrid Synergy Drive is arguably the most advanced and efficient hybrid technology on the road today. The numbers alone illustrate Toyota's overwhelming success; the company itself sold 61% of all U.S. hybrids in the second half of 2004 (See Appendix 2). It can be seen in three of Toyota's vehicles – the Highlander, Prius, and Lexus RX 400h – and in Ford's Escape. Nissan also recently licensed

Toyota's Hybrid Synergy Drive Technology for upcoming use in its Altima Hybrid (Stone). Porsche has even approached Toyota about licensing the technology (Tsukimori). Instead of developing their own technology, these other competing automobile manufacturers are licensing solely Toyota's technology, which is a certain sign that Toyota must have the most attractive technology on the market today.

Stated simply, Hybrid Synergy Drive allows a vehicle to drive on electric power alone, gasoline power alone, or a combination of the two. This technology is considered a full hybrid, or a combination of a series hybrid and parallel hybrid (Irick). Hybrid Synergy Drive is offered in a few variations, depending on the vehicle in which it is offered. The Toyota Prius only has two electric motors (See Appendix 3), but the Toyota Highlander and Lexus RX 400h have three. Understanding the latter variant's hybrid system satisfies the timeliness of this report, so its functionality will be explored in this section.

The 2006 Lexus RX 400h is powered by four separate sources utilizing Toyota's Hybrid Synergy Drive. First, it has a conventional 3.3-liter V-6 gasoline engine, mounted under the hood in the traditional setting. Next, it has three electric motors that can drive the car, dub as generators if needed, or recharge the battery, depending on how the computer attributes each motor's function. The first motor, named MG1 by Lexus engineers, is located in the front of the vehicle and has several duties. It is responsible for starting the gasoline engine when required, serving as a generator when necessary, and controlling a gearset that varies the relationship between the V-6 engine and itself. A second electric motor, MG2, is located near the front transaxle, which has several more responsibilities of its own. First, it must drive the car on its own if the computer allocates

this function. If it is not driving the car alone, it adds torque to the gas engine, providing extra power. Next, it must serve as a generator to recharge the battery pack, located under the floor. Third, this second engine is connected to the second gearset, “which provides the stepless ratio changes across the system’s operating range” (Winfield, 98). In summary, this motor takes the computer’s commands, allowing various components to work together or independently of one another. The third electric motor is hooked to the rear differential, driving the rear wheels and transmitting torque produced by the engine and other motors (Winfield, 98).

Hybrid Synergy Drive also includes regenerative braking, which is a system that recaptures power that would be lost in braking maneuvers. In non-hybrid cars, power is always lost in driving, as it is transferred from the engine to the wheels and never recaptured. However, Toyota uses regenerative braking to recharge the battery pack, which in charge provides more juice for the electric motors. Thus, power is not always completely lost with Hybrid Synergy Drive.

Toyota’s use of regenerative braking creates an interesting inverse relationship between city and highway miles per gallon. Since braking recharges the battery, causing a higher state of charge, city driving allows for higher fuel economy than highway driving. The electric motors are charged more often, which means that the gas engine operates at a lesser capacity, if at all, improving fuel economy. On the highway, the Hybrid Synergy Drive will operate at a lower state of charge due to less braking, meaning that the battery will not be recharged as often. When it reaches a low enough state of charge, the computer will open the throttle, and the gas engine will recharge the battery itself, which will use gasoline and will consequently decrease fuel economy (Irick).

All of these functions are controlled by one supercomputer, as opposed to many microcomputers as seen in many other automobiles. This supercomputer manages all the motors, the gas engine, and the braking system, creating a 'synergy' that could never be achieved if the components were to work independently of one another. The battery's state of charge and the power usage are displayed on a screen, which indicates to the driver how much power is available at any given moment (Irick).

As is true with any hybrid, Toyota's Hybrid Synergy Drive not only increases the fuel economy (miles per gallon), but it increases a vehicle's efficiency. The amount of work out divided by the fuel energy in measures a machine's efficiency. Hybrids by nature require less fuel energy in for the same amount of work out, so they are more efficient than traditional gasoline engines (Irick).

A thorough understanding of Hybrid Synergy Drive is necessary to gain a true appreciation of Toyota's hybrid technology. Hybrid Synergy Drive has introduced a superior technology that answers many consumers' needs and concerns. Toyota has inspired other companies such as General Motors and Daimler Chrysler to participate in the 'green race' and develop their own hybrid technology that will decrease pollution and save oil. Toyota is the leader.

### **Today's Hybrid Market**

The U.S. hybrid market is growing rapidly. The hybrid automobile is transitioning from the introductory phase to the growth phase in its product life cycle. Sales tripled in 2004 to nearly 1% of all automobiles sold in the United States (See Appendix 2). The economy is experiencing little improvement as oil prices continue to

rise and the Fed increases interest rates. Americans are consequently spending less money and are increasingly looking for an automobile that achieves better fuel economy.

Barriers to entry have been high but are diminishing as licensing other technology is becoming more acceptable. Developing hybrid technology requires the commitment of billions of dollars in research and development. Toyota has been the leader by sales volume in the hybrid market, and has just recently announced that it is finally beginning to see a profit on its hybrid automobiles. With the help of its increased sales and licensing opportunities, Toyota is seeing increased net income in a market that has been losing money since its inception.

Competition is increasing as the potential for profit is realized in the hybrid market. Available as early as 2007, Daimler Chrysler and General Motors are partaking in a joint venture to develop their own full hybrid technology that will be similar to Toyota's Hybrid Synergy Drive ("GM, DCX Share"). Ford and Nissan already have hybrids on the market and in testing, respectively. Honda has had their mild hybrids available for 5 years now, and is adding new models frequently.

This increasing competition is resulting in increasing buying power for consumers. Hybrid customers have often been forced to pay a dealer premium to drive a hybrid off the lot immediately. Dealer waitlists have grown from six months to one year for the Toyota Prius in many markets. More competition signifies more options for consumers, and will eventually drive prices on hybrids down. The buying power of consumers has an inverse relationship with selling power of suppliers. Thus, selling power of hybrid manufacturers is decreasing due to the fact that consumers could be lost to competitors.

The threat of substitutes has been quite low, but diesels are increasingly being viewed as possible substitutes in America. Diesels are inherently more efficient because they burn fuel in a different manner. In decades past, diesels have held the stigma that they are louder, pollute more, and emit soot. Recent strides in diesel engine technology and cleaner fuel have mitigated each of these issues. The Mercedes E320 CDI registers virtually the same decibel level as its gasoline engine counterpart the E350. The engine is so advanced that no soot can be seen or smelled by the bystander. Pollution of diesel engines is no worse to the planet than the emissions from gasoline engines, but it affects different aspects of the atmosphere. In terms of global warming, diesels actually contribute less than gasoline engines. Instead, the particulate matter in the exhaust is the detrimental emission, which is a result of sulfur levels in the fuel. By the year 2007, the U.S. will have better standards for diesel engines and decreased sulfur levels in diesel fuel, thus lessening the amount of particulate matter emitted into the atmosphere (Davis). Volkswagen offers its Touareg, Passat, and Jetta in diesel engine variants. Mercedes has just introduced its E350 CDI in the United States and is considering bringing a diesel option to the C Class and ML Class. Jeep even offers a diesel variant for its Jeep Liberty. What must happen before diesels are accepted as a true substitute to the hybrid is a transformation of America's attitude, which cannot happen overnight.

### **The Future**

The future of the hybrid automobile heavily depends on its acceptance with consumers. If consumers demand greater quantities of hybrids, manufacturers have



shown that they will produce them. The trend currently leans in favor of the survival of hybrids.

An analogy can be drawn between the future of hybrid automobiles and the progression from the VHS cassette to DVD technology. Many wonder whether hybrids will become the DVD's of the automobile industry or whether they will become the highly unsuccessful laserdiscs. At this juncture, the internal combustion gasoline engine does not have a definite future as the sole engine source for automobiles just as VHS cassettes did not have a strong future for movie viewing and recording devices in the 1980's. Technology progresses and resources will eventually be depleted.

Toyota plans on the hybrid engine becoming the next DVD for the automobile industry. Toyota will manufacture 300,000 hybrids in 2005, increasing production of its Prius to 180,000. It is spending \$6 billion per year on research and development, about half of which is going toward the environment. Toyota's objective is to eventually reach cost parity between a hybrid automobile and a conventional vehicle, but it recognizes that strides must be made. Above all else though, President Fujio Cho says, "We want to maintain leadership" ("Toyota").

Beyond the hybrid, the future of the automobile industry is unclear. Most industry analysts speculate fuel cells or hydrogen fuel will be the next wave of technology to flush through the industry. Advantages to these technologies are an alternative fuel source from oil, and they essentially have zero emissions. Currently, however, they are merely in the experimental stage. The fueling infrastructure would have to be completely modified to incorporate hydrogen fuel pipes, pumps, and tanks.

The capital required for such an extraordinary project would have to be subsidized by the government, which is a very distant reality.

There are exciting certainties, however, in the automobile industry. Whether or not hybrids are here to stay, fuel economy and engine efficiencies will continue to improve with technology and depleting oil on the planet. The cars we will be purchasing tomorrow will continue to be more entertaining to drive, and they will continue to be more environmentally friendly. Hybrids are the beginning of a great new trend that will have a permanent impact on the automobile industry.

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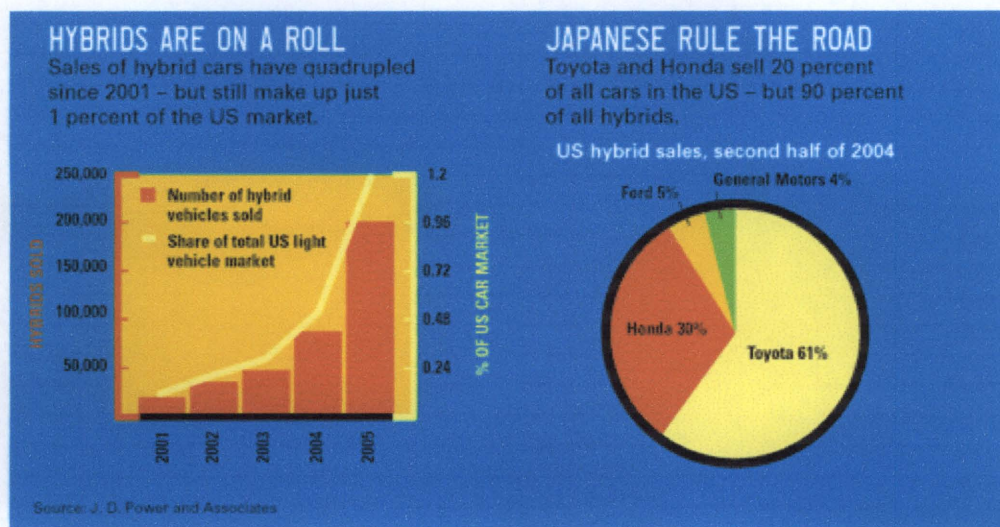
## Appendix 1

| HYBRID SCORECARD           |                |                      |                       |                        |              |                   |              |
|----------------------------|----------------|----------------------|-----------------------|------------------------|--------------|-------------------|--------------|
| MAKE & MODEL               | BASE PRICE     | MILEAGE (CITY / HWY) | ENGINE & HP / TORQUE  | 0-60 TIME (IN SECONDS) | INTRODUCED   | 2004 UNITS SOLD   | RATING (1-5) |
| Ford Escape Hybrid         | \$26,380       | 36 / 31              | 2.3L I-4, 155 / 129   | 8.9                    | 2004         | 2,993             | 4            |
| Honda Accord Hybrid        | \$29,990       | 30 / 37              | 3.0L V-6, 255 / 232   | 6.7                    | 2004         | 1,061             | 4            |
| Lexus RX 400h              | \$49,000 (est) | 30 / 26              | 3.3L V-6, 268 / (n/a) | 7.3                    | 2005         | Not yet on market | 4            |
| Toyota Prius               | \$20,875       | 60 / 51              | 1.5L I-4, 110 / (n/a) | 10.0                   | 1997 (Japan) | 53,991            | 3.5          |
| Honda Civic Hybrid         | \$19,800       | 46 / 51              | 1.3L I-4, 93 / 116    | 10.9                   | 2001 (Japan) | 25,575            | 3            |
| Honda Insight              | \$19,330       | 60 / 66              | 1.0L I-3, 73 / 79     | 10.6                   | 1999         | 585               | 2.5          |
| Chevrolet Silverado Hybrid | \$30,345       | 18 / 21              | 5.3L V-8, 295 / 335   | 8.2                    | 2004         | 1,500             | 2            |
| Toyota Highlander Hybrid   | \$33,680 (est) | 32 / 27              | 3.3L V-6, 268 / (n/a) | 7.3                    | 2005         | Not yet on market | (n/a)        |

Specifications provided by car manufacturers; 0-60 times for Chevy, Ford, and Honda from Car and Driver magazine

Source: Eisenstein, 105

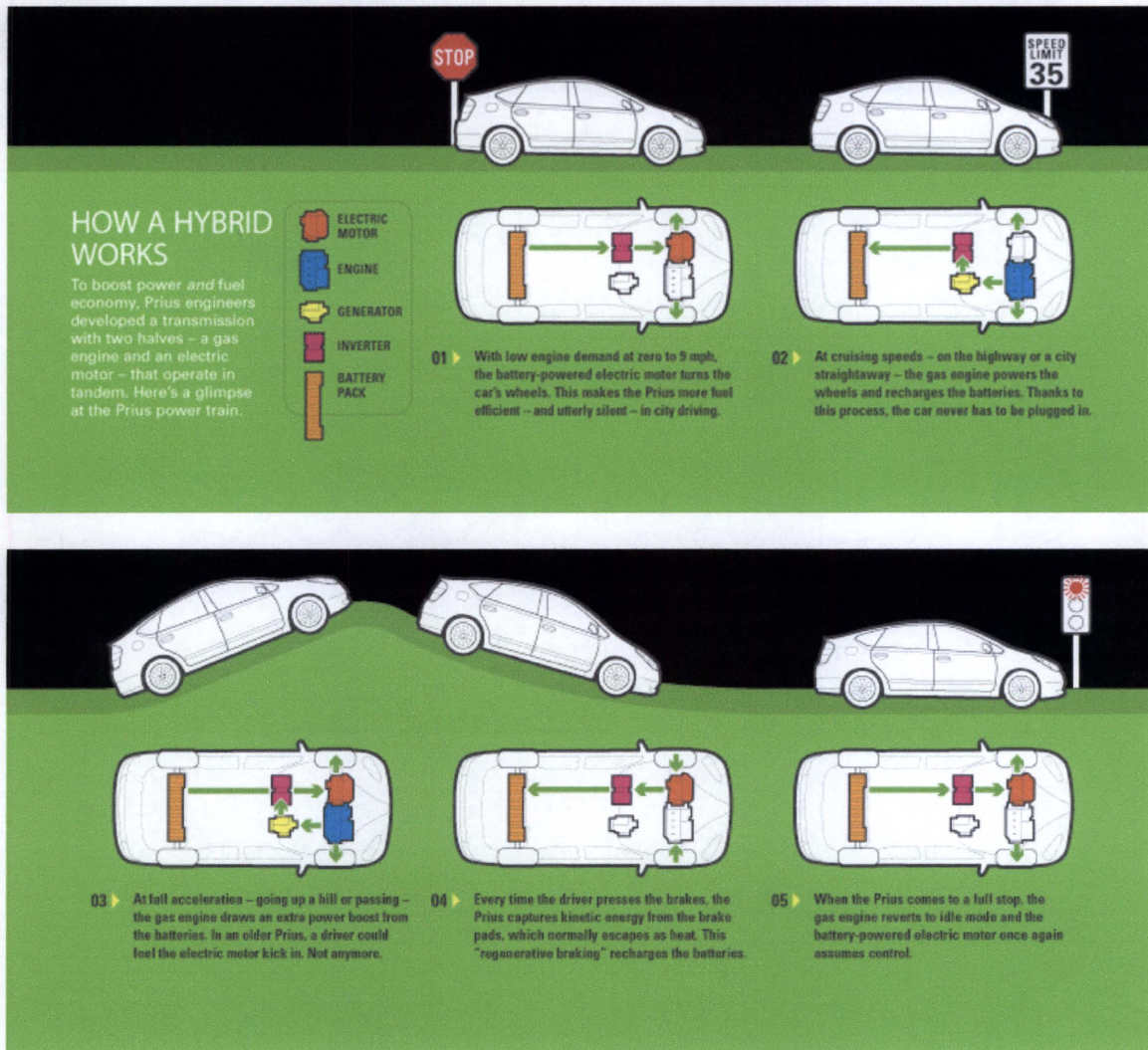
## Appendix 2



Source: Koerner, 101



## Appendix 3



Source: Koerner, 98-99